CHARACTERIZATION OF deterioration ON THE shotcrete lining IMMERSED IN VARIOUS SULFATE SOLUTIONS

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ABSTRACT

This study is to evaluate the characterization of shotcrete exposed to sulfate solution on long-term. Surface examination, compressive strength test, adhesive strength test and micro-structural analysis were performed to analyze the deterioration of shotcrete specimens, which were cored at cast-in-place shotcrete lining. The shotcrete specimens were immersed in 1, 2, and 5% of sodium sulfate solutions upto 60-weeks. From the test results, the compressive strength and adhesive strength of shotcrete specimen increased up to 56 days of immersion period. The reason was that the cement matrix was densified in filling the pore of shotcrete with cement hydrate products in the early age of immersion period. After 56 days of immersion period, the compressive strength and adhesive strength decreased with increasing immersion period of shotcrete specimens in sodium sulfate solutions. The deterioration of shotcrete was caused by the gypsum, ettringite, and thaumasite formation in the shotcrete specimens. These results were confirmed by XRD, SEM and EDS analyses.

1. INTRODUCTION

In general, the tunnel structure is commonly constructed in the ground or rock bed, and shotcrete for the support of underground excavations has widely been used in mining engineering and civil engineering because the shotcrete is no dependant upon the shape of cross-section of tunnel. The shotcrete of the tunnel can contact with groundwater because the tunnel is constructed in the ground. The hazardous materials found in the groundwater may deteriorate the engineering properties of shotcrete, such as compressive strength, adhesive strength, and flexural strength. The volume of sulfate ion contained in the soils in Korea differs according to area and environmental conditions. The ground in Korea contains the sulfate ion about 0.01 ~ 0.1% in most areas.

In this regard, it was performed the following tests for evaluating the erosion of shotcrete resulted from the sulfate ion contacting the tunnel support materials. The compressive strength of shotcrete

and adhesive strength between shotcrete and rock were measured on the shotcrete specimens immersed in the three different sodium sulfate (Na_2SO_4) of 1, 2 and 5%. Also, mechanical analyses, such as XRD, SED and EDS analyses were conducted to evaluate the change the micro-structure of shotcrete deteriorated by sodium sulfate.

2. SAMPLE AND TESTING METHOD

2.1 Sample Preparation

Portland cement (OPC) on the basis of KS(Korea Standard) L 5201 was used for preparing shotcrete samples. Its specific gravity was 3.15. The large aggregate of 13mm (specific gravity: 2.60) and small aggregate (specific gravity: 2.59) were used for this study. Accelerator with aluminate was used, and its weight was 5% of total weight of cement. The design compressive strength of shotcrete was 21MPa at 28days. Table 1 shows the mixture proportion for shotcrete.

Table 1. Mixture proportion of shotcrete

$f_{ck,}$ (MPa)	G_{max} (mm)	Slump (cm)	W/C	S/a	Unit weight, kg/m^3				Superplasticizer, kg
					W	C	S	G	
21	13	10	0.45	0.62	204	453	1132	572	2.27

In order to evaluate the compressive strength of shotcrete as well as the adhesive strength between shotcrete and rock in the harmful environment, the rock sample (granite) was installed in the rectangular mold (250×500×200mm) made of steel. The shotcrete was sprayed on the rock sample in the mold inside the tunnel construction site and cured in the air for 28 days. The specimen for this study was cored with the diameter of 55mm.

2.2 Testing Method

1) Compressive strength test: the compressive strengths of shotcrete immersed in the sodium sulfate solution and water were measured according to KS F 2405 and F 2422. At each immersion date, three specimens were used for measuring the compressive strength of shotcrete.
2) Adhesive strength test: the direst tensile test according to ASTM D 2936 and C 1404, were conducted to measure the adhesive strength of shotcrete. The glue type method, using the epoxy, was adopted for adhesive strength test.
3) XRD (X-ray diffraction) analysis: X-ray diffraction analysis was performed to evaluate the product resulted from the action of shotcrete under the conditions of CuK(Ni, filter) 35kV, 20mA, Scanning speed 80/min, Full Scale 14cps, $2\Theta = 5 \sim 60°$.
4) SEM and EDS analysis: This analysis was conducted by using the Philips XL 30 ESEM for the scanning electron microscope. The micro-structure was observed by using the EDS (Energy Dispersive X-ray Spectroscopy) type electron microscope analyzer at the same time of SEM

Analysis.

5) Test solution: The sodium sulfate (Na_2SO_4) solution of 1%, 2% and 5% were prepared to evaluate the sulfate erosion characteristics of shotcrete. All solutions were replaced every other week to reduce the dilution of density.

3. RESULTS AND ANALYSIS

3.1 Strength of Shotcrete

The shotcrete specimens were immersed in the sodium sulfate solution of 1%, 2% and 5% to evaluate the strength of shotcrete exposed to the sulfate environments. Figure 1 shows the compressive strengths of shotcrete immersed three different sodium sulfate solutions and water for immersion period, from 0th day to 245 days.

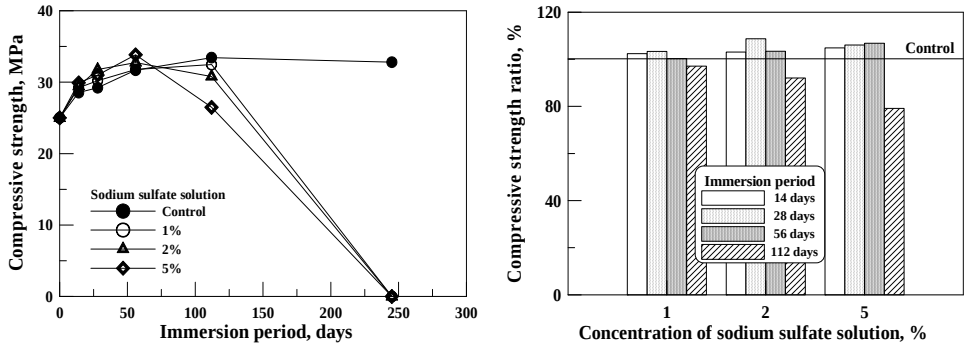


Figure 1. Compressive strength and compressive strength ratio of shotcrete immersed in the sodium sulfate solution

As shown in Figure 1, the compressive strength of shotcrete immersed in the sodium sulfate solution was higher than that of shotcrete cured in the water during immersion 56 days. This is because the ettringite, which was the expansive substance generated by the sulfate ion reacting with cement hydration product, filled with pore of cement matrix. However, the compressive strength decreased after immersion 56 days and shotcrete specimens were collapsed at immersion 245 days. It is not available to perform the compressive strength test. This is because, when the immersion period increased, expansive substance gradually made the expansive cracks on the surface of specimen, and generated the gypsum softening the shotcrete specimen. As shown in Figure 1, the compressive strength ratio, that is, the ratio of compressive strength of shotcrete immersed water to that of shotcrete immersed in the sodium sulfate solution, decreased with increasing the immersion time. The compressive strength ratio decreased with increasing the density of solution.

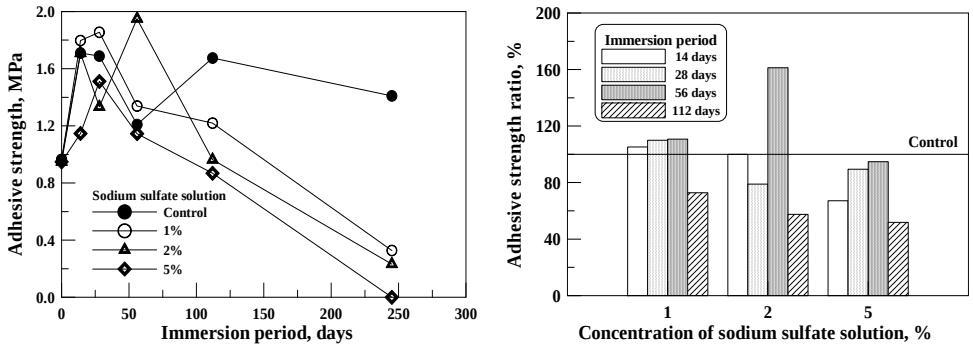


Figure 2. Adhesive strength and adhesive strength ratio of shotcrete immersed in the sodium sulfate solution

Figure 2 shows the adhesive strength between shotcrete and rock sample immersed in the sodium sulfate solution of 1, 2 and 5% and water during 0, 14, 28, 56, 112 and 245 days. The adhesive strengths of shotcrete immersed in the three different sodium sulfate solutions and water increased with increasing immersion time. As mentioned above, the internal texture of shotcrete was getting compact by expansive substance, such as ettringite, and then adhesive strength of shotcrete had increased during early immersion period. The adhesive strength of shotcrete immersed in the three different sodium sulfate solutions began to decrease from immersion 56 days. The adhesive strengths of shotcrete immersed in the sodium sulfate solutions were lower than those of shotcrete cured in the water at immersion 112 days. The adhesive strength decreased with increasing the density of sodium sulfate solution. The deterioration had been severely progressed in the shotcrete specimen immersed in the sodium sulfate solution of 5% at immersion 245 days. So, it is not available to measure the adhesive strength of shotcrete as shown in Figure 3. The shotcrete specimens immersed in the sodium sulfate solution of 1% and 2% show the similar tendency.

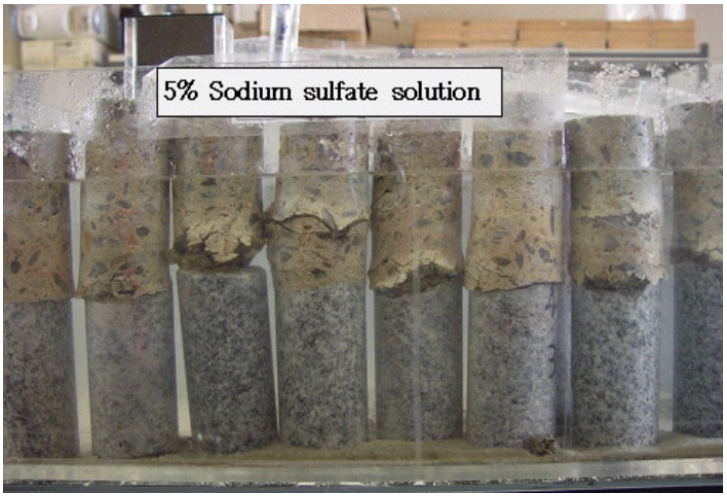


Figure 3. Shotcrete specimens immersed in the 5% sodium sulfate solution at 245 days

3.2 XRD Analysis

Figure 4 shows the results of XRD analysis conducted on the shotcrete specimen immersed in the sodium sulfate solutions and water for 32 weeks to evaluate the reaction product of shotcrete exposed to the sulfate.

The shotcrete cured in the water had the portlandite, which is important hydration product of cement, and quartz and feldspar by aggregate. In the case of the shotcrete immersed in the sodium sulfate solutions, the peak of portlandite was not detected by the dissolution of C-S-H.

On the other hand, when the density of sodium sulfate increased, some different peak value was observed. The gypsum, brucite, ettringite and thaumasite were detected.

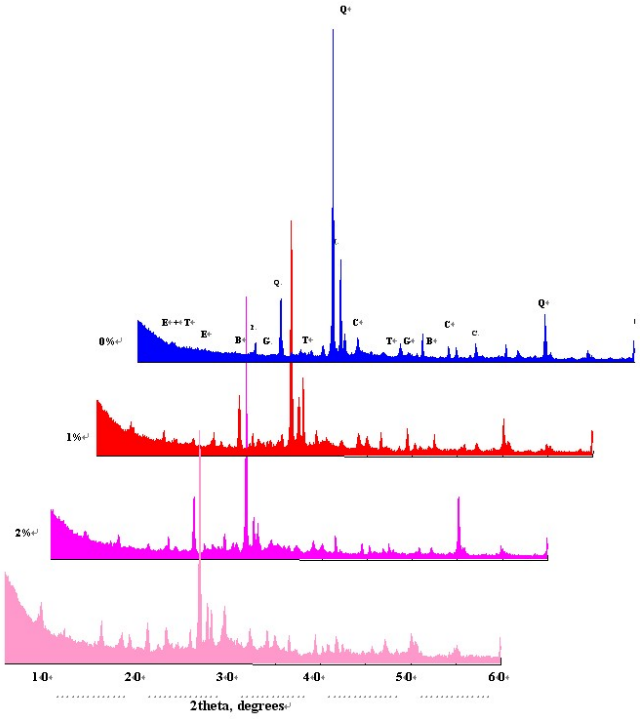


Figure 4. The results of XRD analysis

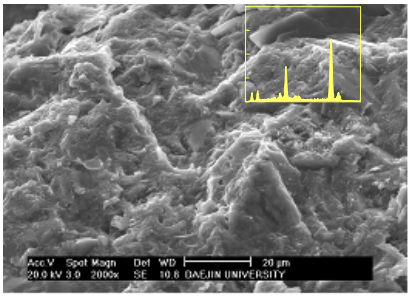
3.3 SEM and EDS Analysis

Figure 5 shows the results of SEM and EDS Analysis on shotcrete specimens cured in the water and immersed in the sodium sulfate solution for 32 weeks after zooming up 2,000 times. As shown in Figure 5(a), the shotcrete specimen cured in the water show that the texture of specimen was compact and no fine crack was observed. The specimen had C-S-H hydrate generated. In the case of the shotcrete specimen immersed in the sodium sulfate solution, the ettringite with needle shape was observed and portlandite was detected. The hydration texture of this specimen was not compact as compared with that cured in the water. From the EDS analysis, the reaction products, such as ettringite, thaumasite, brucite and gypsum, were observed. The results of EDS analysis corresponds with the one of XRD analysis.

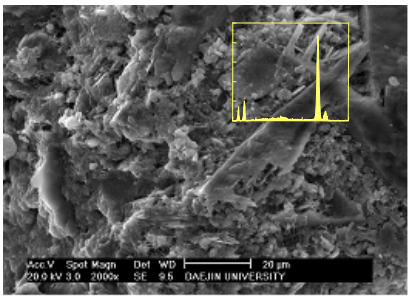
4. CONCLUSION

In this study, engineering properties and micro structure change of shotcrete deteriorated sodium sulfate were analyzed. The reviewed results are summarized as follows:

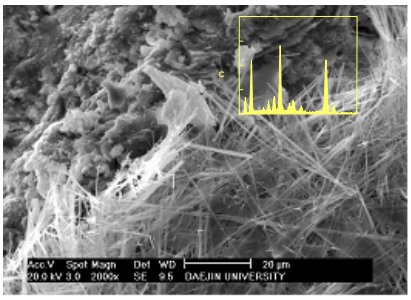
The compressive strength of shotcrete and adhesive strength between this shotcrete and rock immersed in the three different sodium sulfate solutions were stronger than those immersed in the water regardless of density of sodium sulfate solution until immersion 56 days. The compressive strength and adhesive strength of shotcrete were rapidly decreased after immersion 56 days. As the immersion period was getting longer, the sulfate ion reacted with cement hydration product, and expensive substances, such as ettringite and thaumasite, were generated. Such substances made the expensive crack on the surface, and generated the gypsum softening the shotcrete. These reaction products were checked or verified through the results of XRD, SEM and EDS analysis.



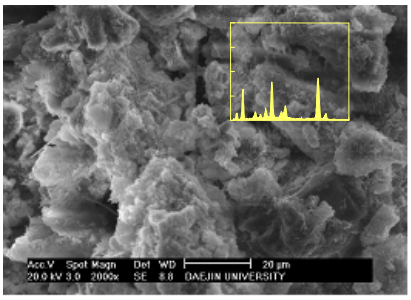
(a) Tap water



(b) 1% sodium sulfate



(c) 2% sodium sulfate



(b) 5% sodium sulfate

Figure 5. The results of SEM and EDS analysis

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